Lawrence Livermore National Laboratory

SCRAAM: The Southern California Reactor Antineutrino Anomaly Monitor

N. Bowden, A. Bernstein, T. Classen, S. Dazeley, G. Keefer

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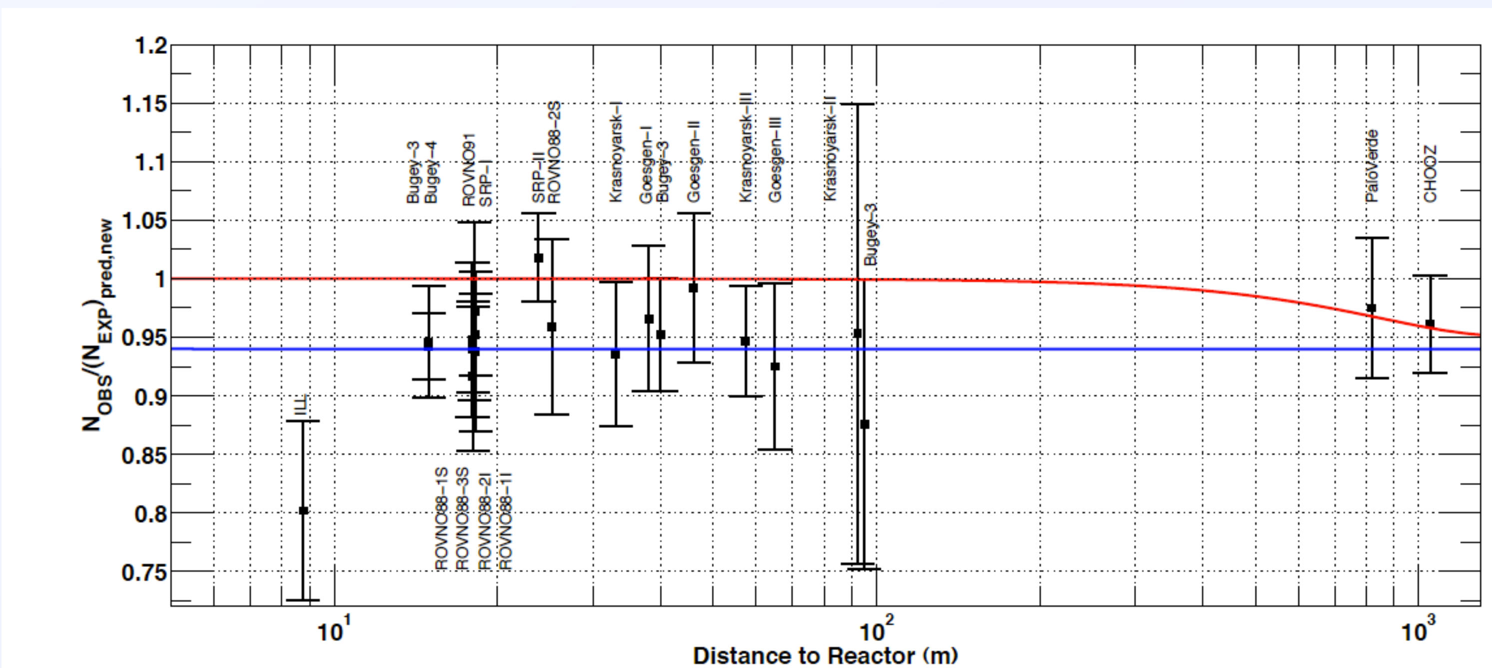
The Reactor Antineutrino Anomaly

- Mention, et al, re-analyzed many previous short baseline reactor experiments, in light of their new antineutrino flux prediction
- The result: new global "Reactor Antineutrino Anomaly" at 2 sigma significance:

$$N_{obs}/N_{pred} = 0.979 \pm 0.029 \Rightarrow 0.943 \pm 0.023$$



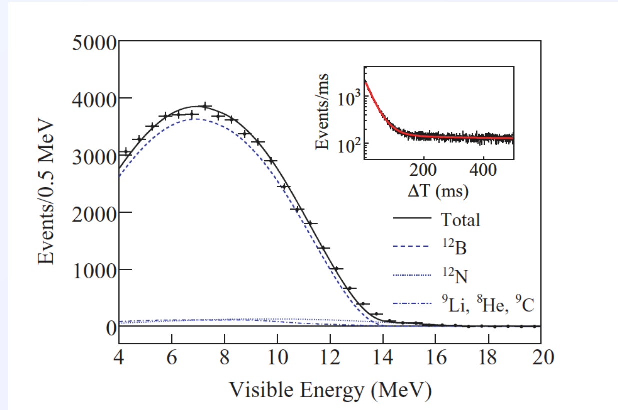
arXiv:1101.2755v4

SCRAAM Proposal

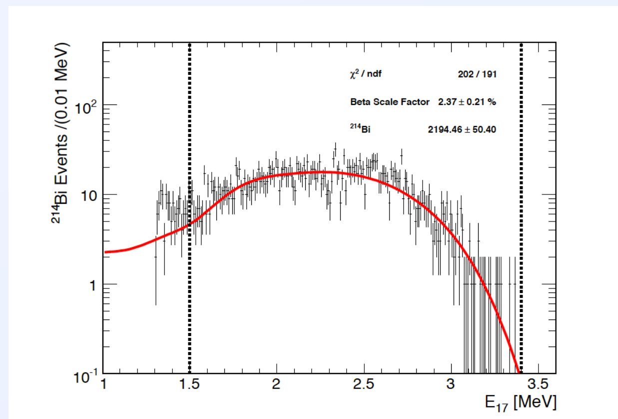
- To test the anomaly, perform:
  - An independent re-evaluation of the antineutrino flux prediction
    - Highly desirable to bolster confidence in the result and examine systematics related to the procedure
  - A relatively rapid and inexpensive experimental measurement
    - requires a location with a high antineutrino flux and appropriate core-detector geometry

Independent Antineutrino Flux Prediction

- Exercise the same methodology as Mueller, et al, but in addition:
  - Incorporate a more precise treatment for generation of fission product beta spectra
    - Code base rigorously tested in KamLAND
  - Examine, via benchmarked reactor simulations, potential systematic related to use of ILL integral electron measurement
    - ILL Research reactor neutron flux differs from that in a PWR
  - Seek to benchmark the fission beta electron spectrum fitting procedure against a non-reactor fissile isotope
    - ^{252}Cf is obvious candidate; would require measurement of ^{252}Cf beta spectrum



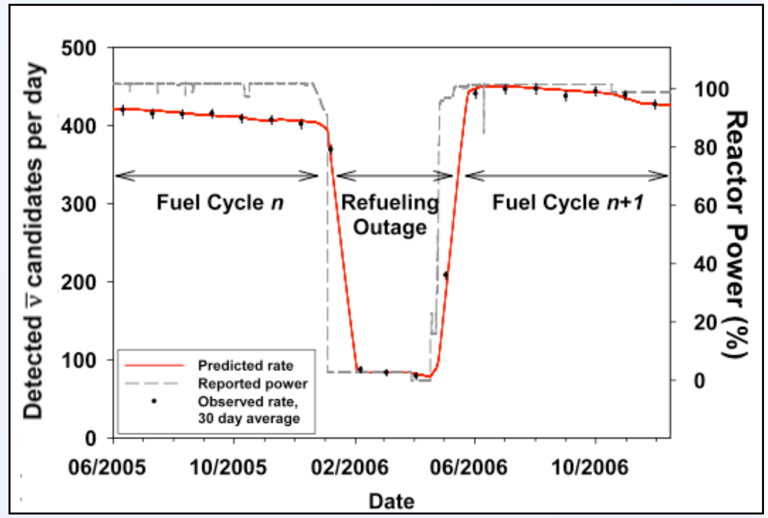
PHYSICAL REVIEW C 81, 025807 (2010)



G. Keefer, PhD Thesis, University of Alabama, 2009

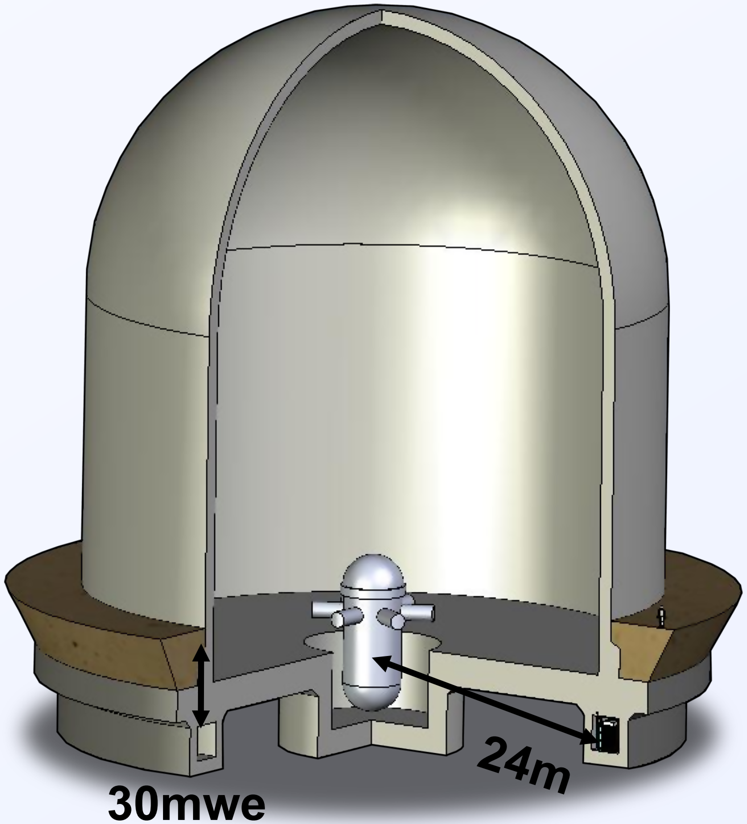
The San Onofre Nuclear Generating Station: Our (nonproliferation) laboratory for over a decade

Direct Observation of reactor fuel burnup via antineutrino counting



- We have cultivated an exceptionally strong and trusting relationship with SONGS:
  - A multitude of access requests have been readily granted since 1999
  - Provide unescorted reactor access, deployment assistance, commercially sensitive fueling data, introductions to other operators, …..
- We possess unparalleled operational experience in this industrial environment:
  - **Five** detector deployments since 2003

Tendon Galleries are Ideal Deployment Locations

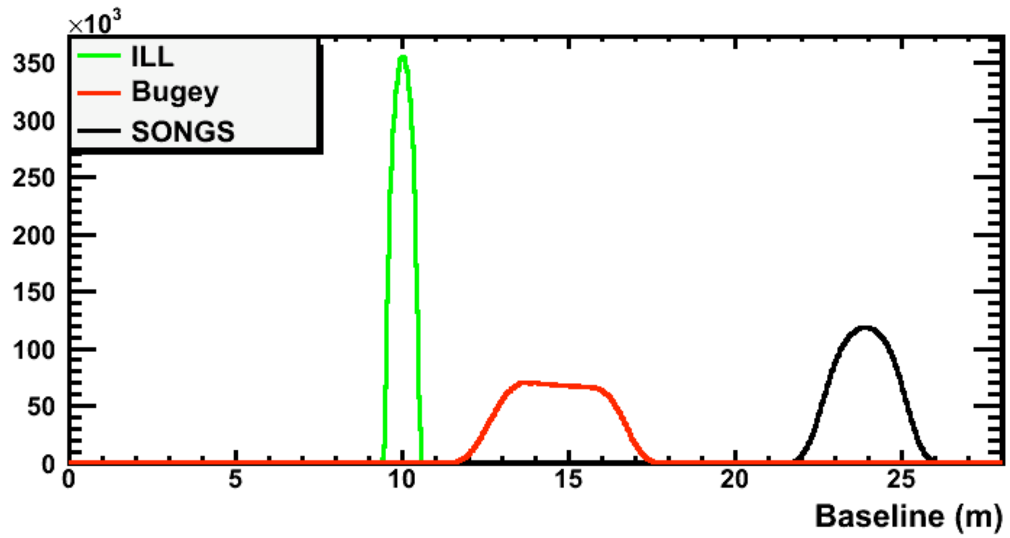


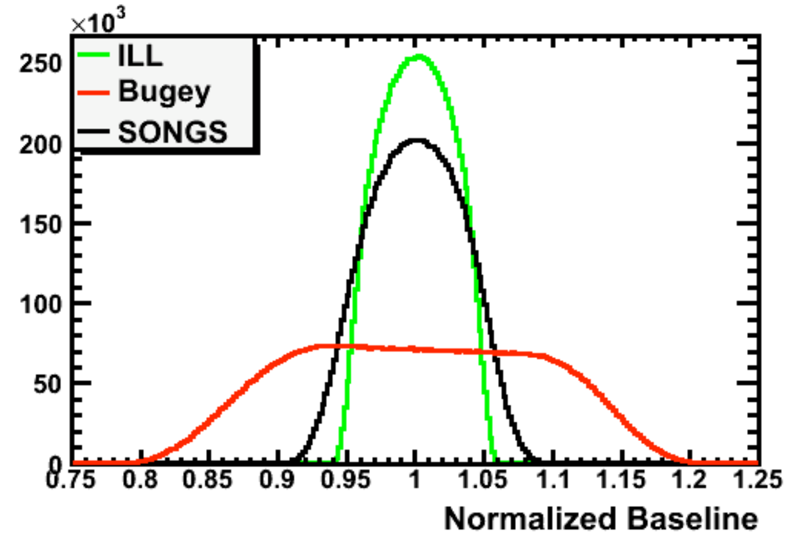
- High Flux: ~10^{17} $\nu/m^2/s$
- 130-180m to other reactor
- Gallery is annular – unfortunately no possibility to vary baseline

Tendon Gallery Access

Reactor Comparison

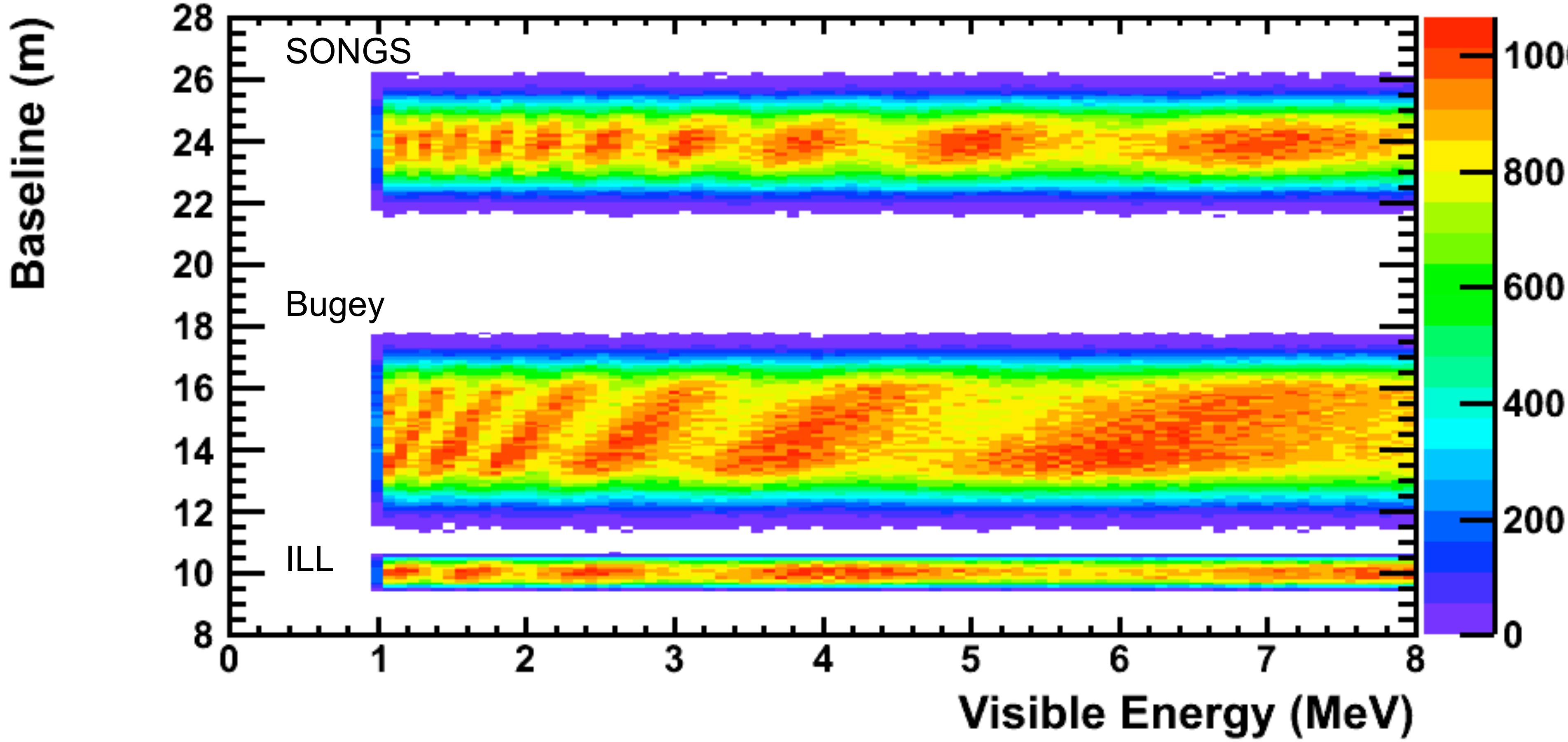
Reactor	Baseline	Core	Detector	ΔL/L (FWHM)	Power	Flux $\nu/m^2/s$
ILL	10m	Ø0.4m x 0.2m (?)	Ø1mx1m	~8%	58 MW_{th}	~$1x10^{16}$
Bugey	15m	Ø2.5 x 2.5m	1mx1m	~30%	2800 MW_{th}	~$2x10^{17}$
SONGS	24m	Ø3m x 2m	Ø1mx2m	~10%	3400 MW_{th}	~$1x10^{17}$





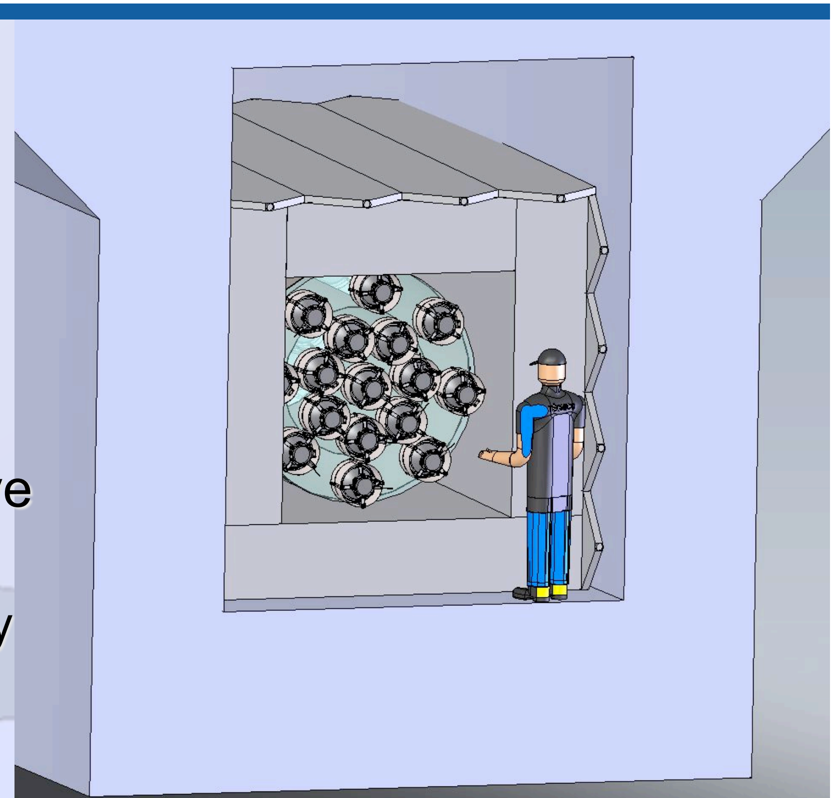
Effect of Baseline, Baseline Distribution

$(\sin^2(2\theta) = 0.165, \Delta m^2 = 2.4\ eV^2)$



The SCRAAM Detector Concept

- A relatively long/narrow geometry is needed: Ø1m x 2m length
  - Tendon gallery is fairly narrow
  - Minimize $\Delta L/L$
- 1.5 ton active mass
  - ~9000 inverse beta interactions/day
- Double ended readout and diffuse reflective coating
  - good light collection and position uniformity
  - should easily achieve 10% energy resolution at 1MeV
- Guide tubes for calibration
- Partial “gamma catcher”:
  - increase efficiency, precision
- Component costs: $700-900k



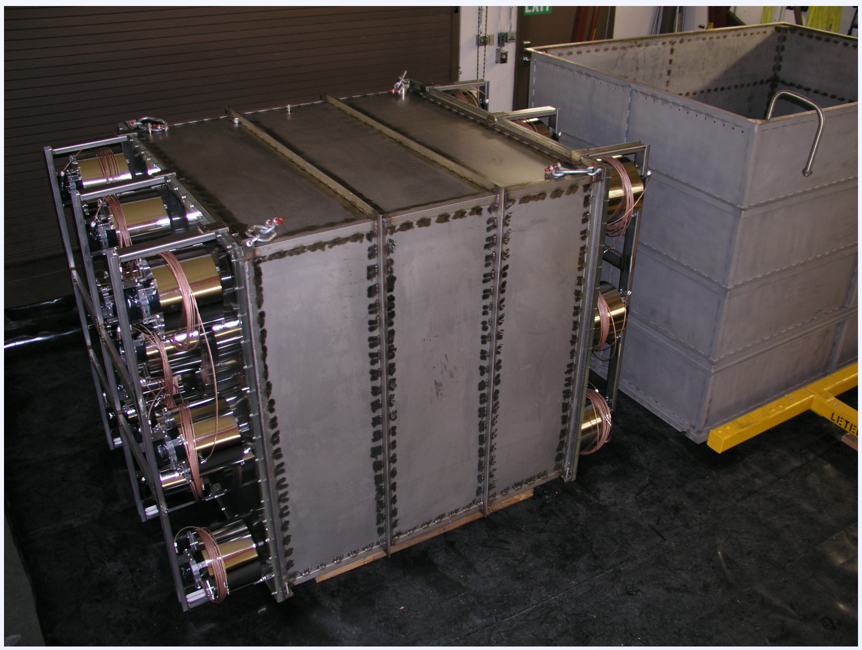
Detection Rate, Detector Systematics

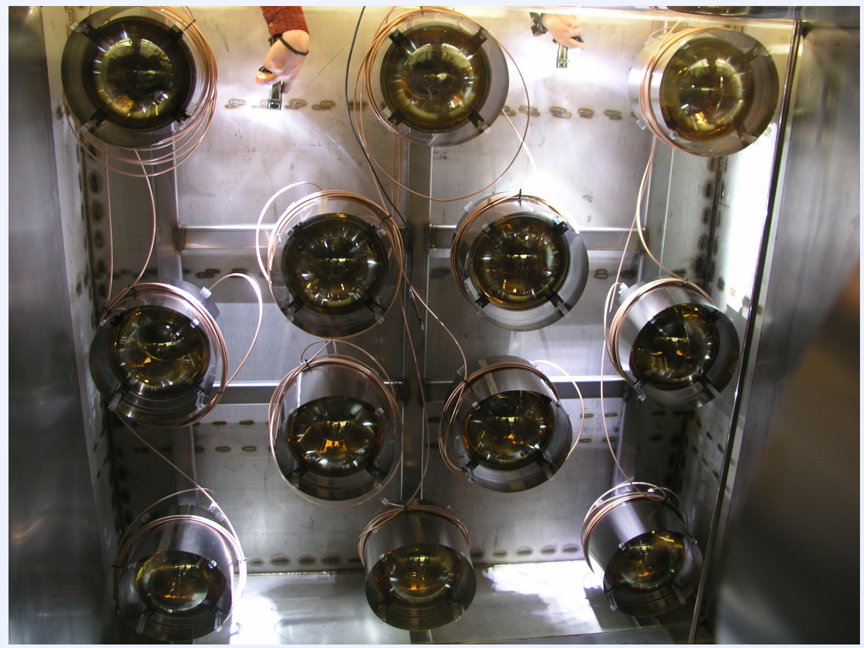
- Assuming 40% efficiency, expect detection rate of about 4000 ν/day
- Precision on absolute efficiency of ~ 4% would require considerable effort, but appears feasible
- Extensive source calibrations would be required

Systematic	Target Value	Mitigation
No. of target protons	1.5%	Weighting, solvent selection
Neutron efficiency	1.5%	Gamma catcher, calibration
Positron efficiency	1%	calibration, ideally $\approx$ 500 keV threshold
Core-Detector distance	0.5%	Through document review, possible survey
Deadtime	0.25%	precise measurement, tracking
Detector Total (Flux Measurement)	2.4%	
Reactor Systematics	2.7%	
Total on N_{obs}/N_{pred}	3.6%	

We have completed considerable R&D on detectors of this scale

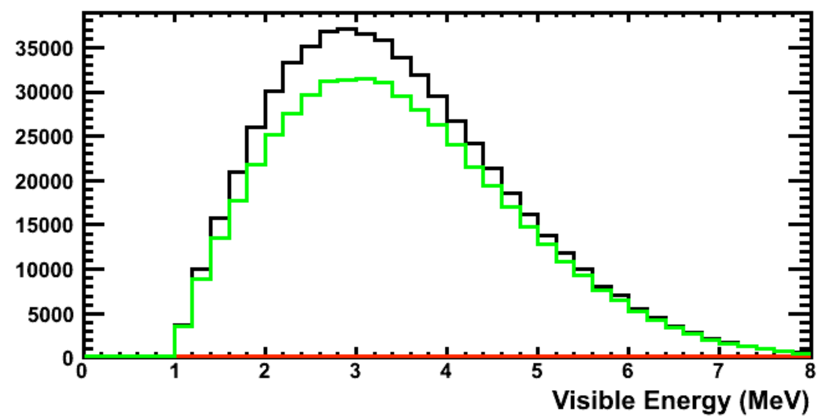
- Most recent: 3.6 ton liquid scintillator detector (BC-525, 0.1% Gd)
  - For deployment at a CANDU6 reactor in 2012
  - Understand safety and regulatory requirements for reactor site
  - Successful commissioning run just completed
  - Validated mechanical design for double ended PMT readout

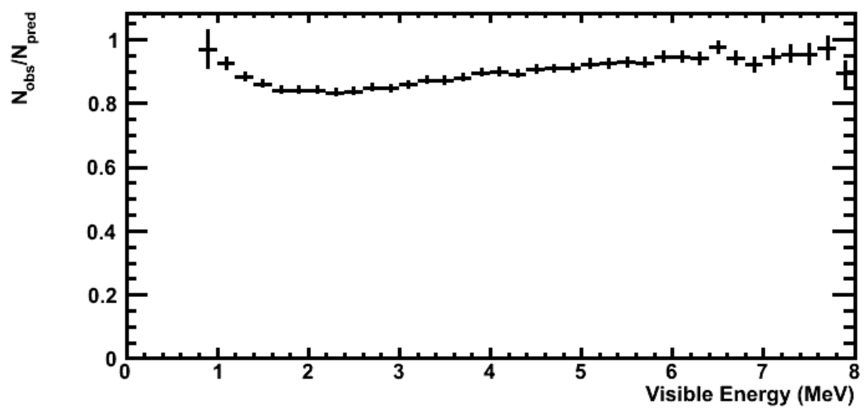




Example Oscillation Patterns

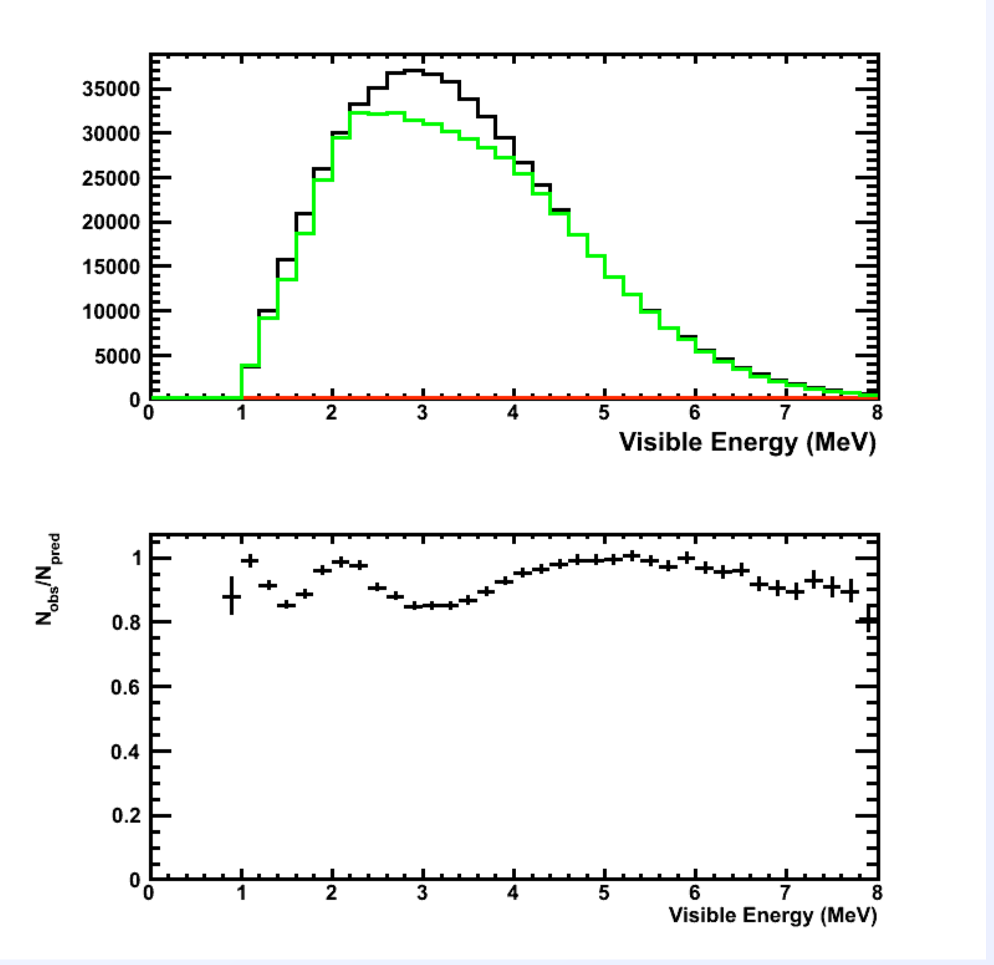
150 days, $\sin^2(2\theta)$ =0.165, Δm^2 =0.15 eV^2





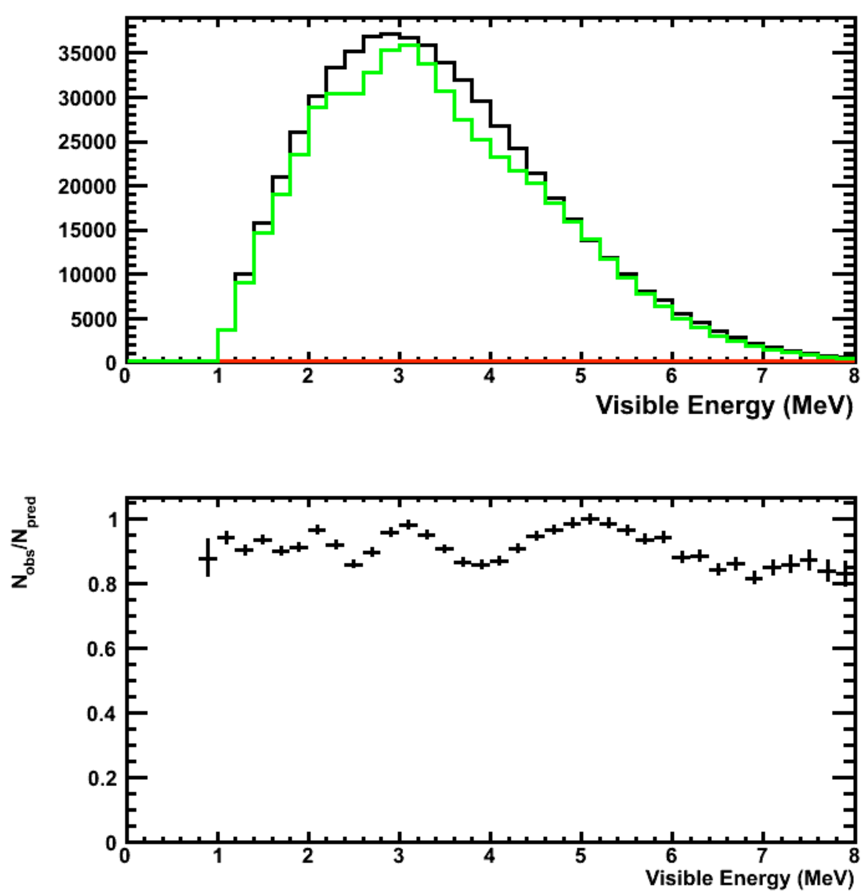
Example Oscillation Patterns

150 days, $\sin^2(2\theta)$ =0.165, Δm^2 =0.6 eV^2



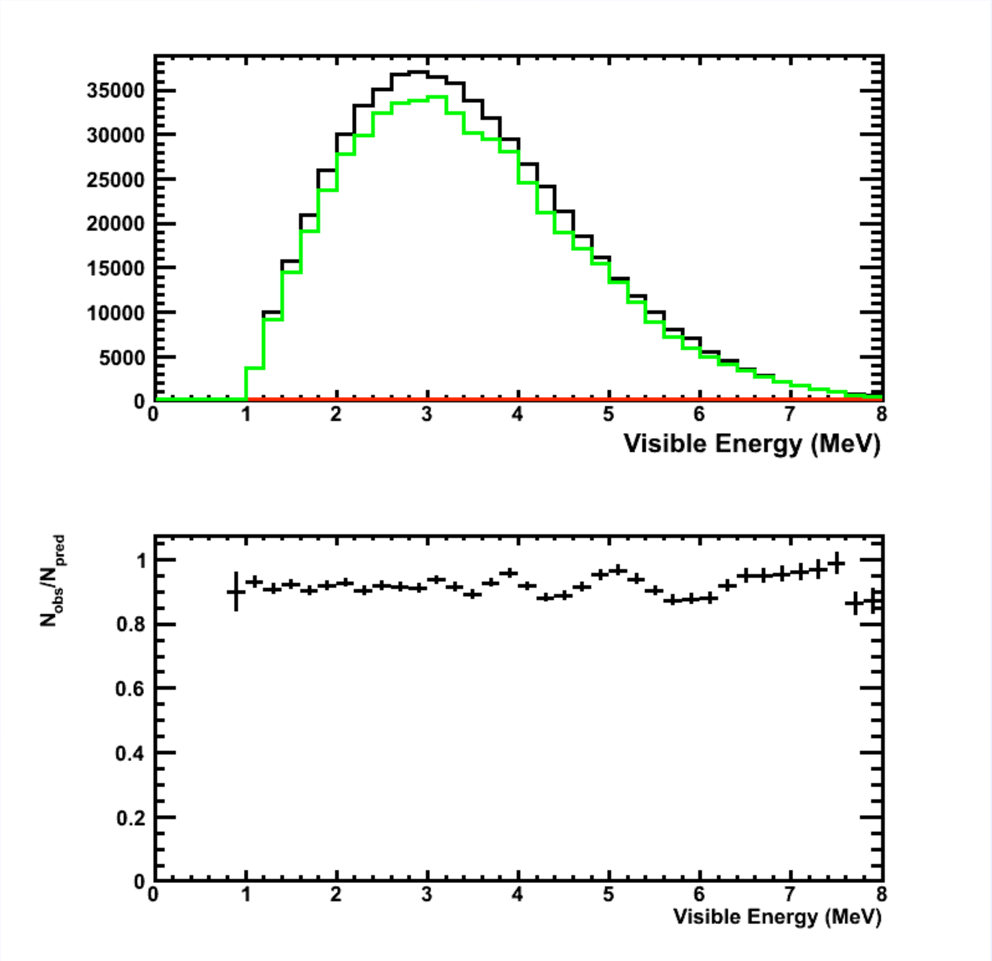
Example Oscillation Patterns

150 days, $\sin^2(2\theta) = 0.165$, $\Delta m^2 = 1.2\mathrm{eV}^2$



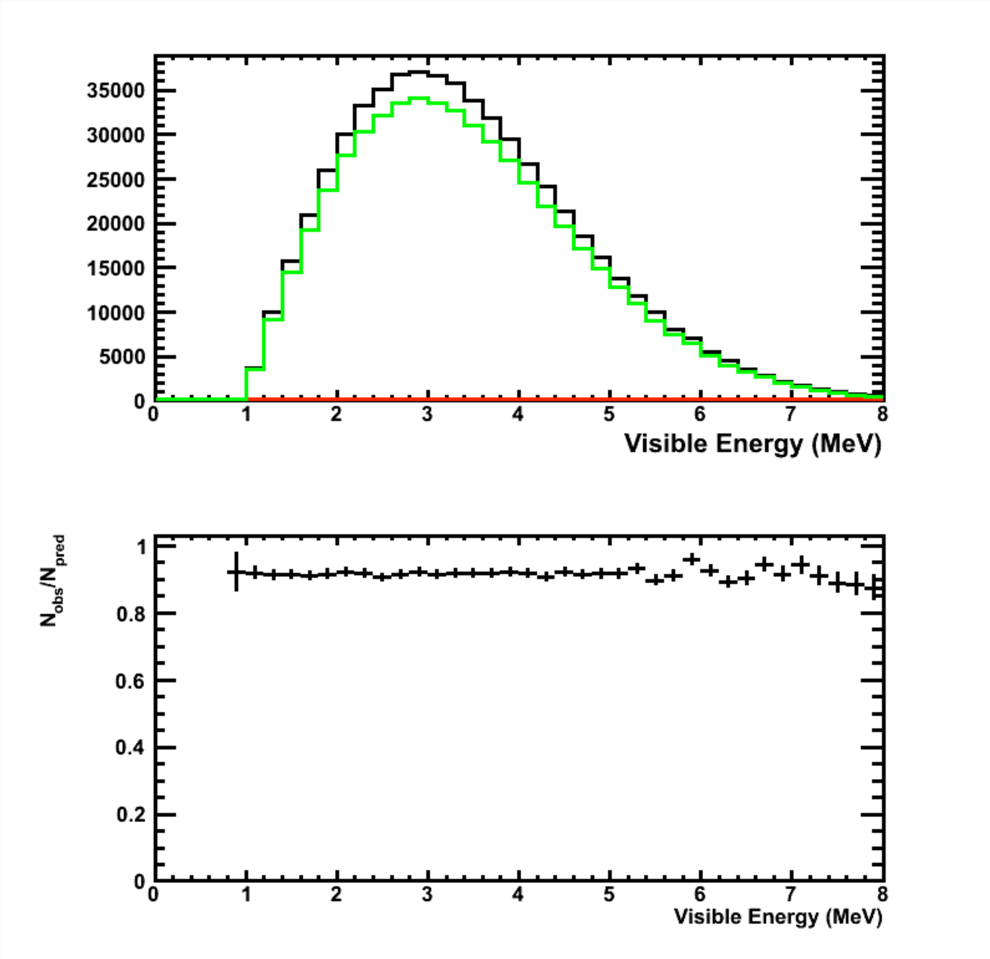
Example Oscillation Patterns

150 days, $\sin^2(2\theta)$ =0.165, Δm^2 =2.4 eV^2



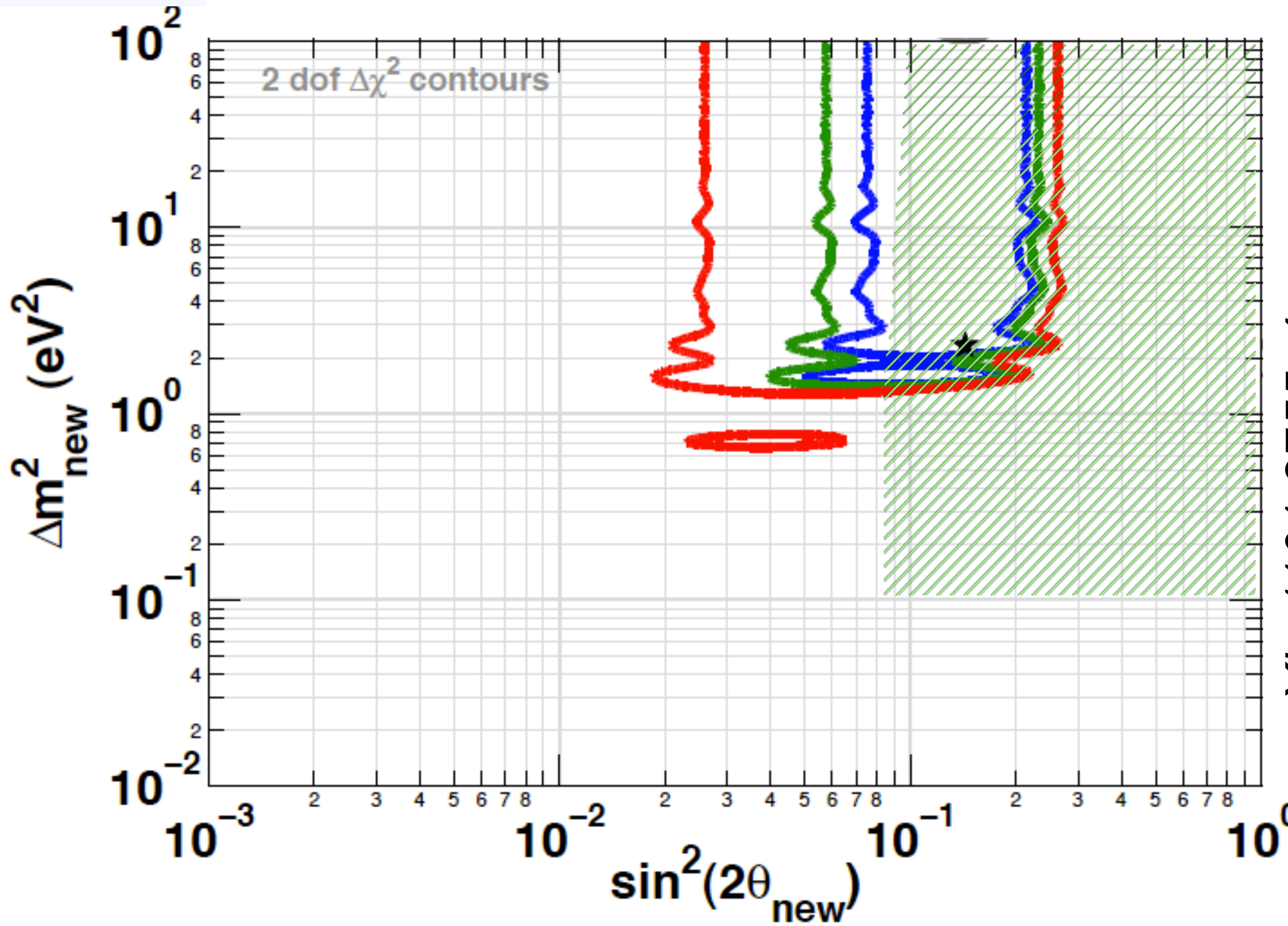
Example Oscillation Patterns

150 days, $\sin^2(2\theta)$ =0.165, Δm^2 =4.8eV^2



Exclusion: Rate

- **150 days, 3.6% systematic (uncorrelated), 99% C.L.**



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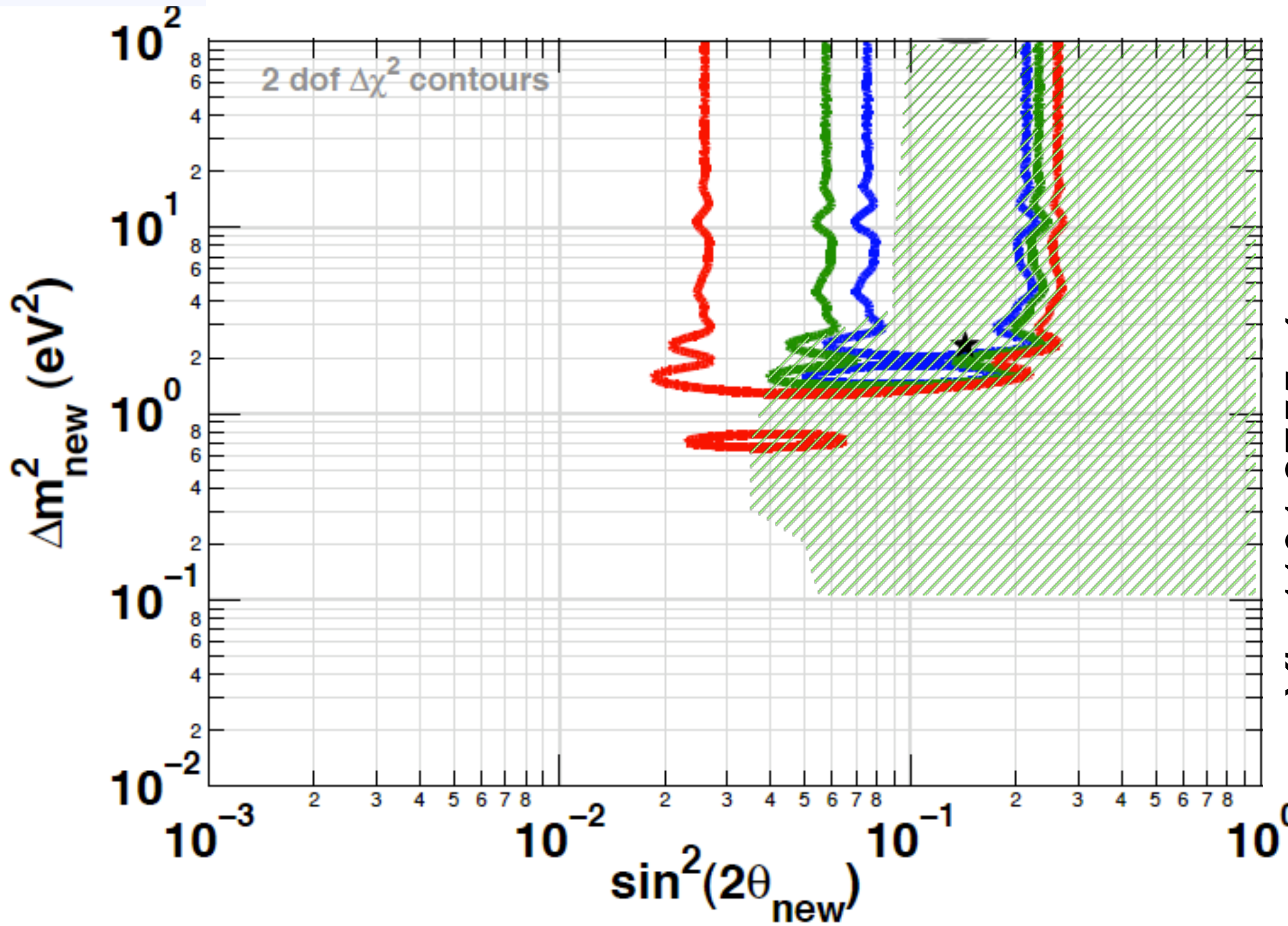
Exclusion: Rate + Shape

- **150 days, 1.5% systematic (bin-to-bin uncorrelated), 99% C.L.**



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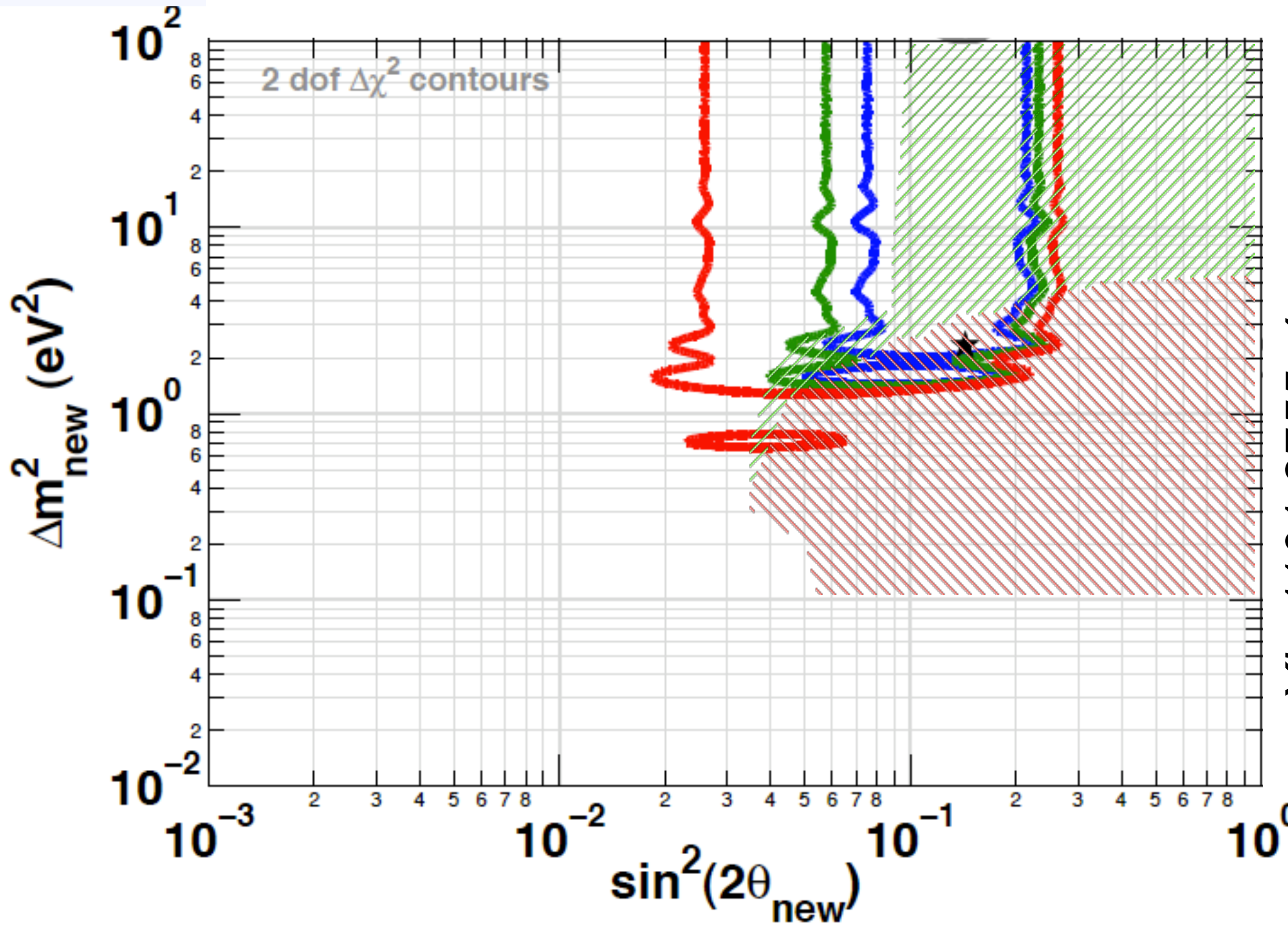
Sensitivity to oscillation parameter values

- **150 days, 1.5% systematic (bin-to-bin uncorrelated), 99% C.L.**



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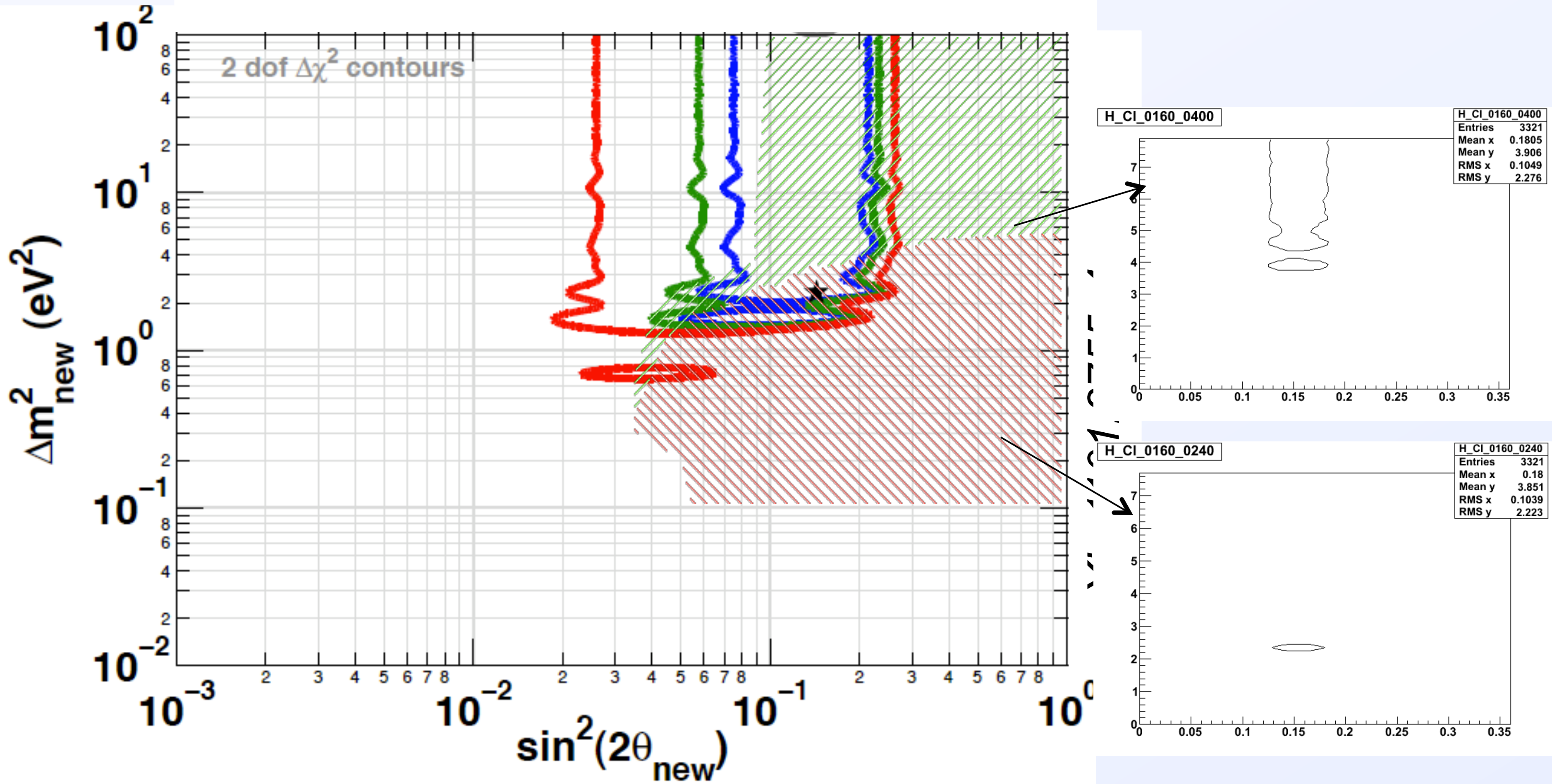

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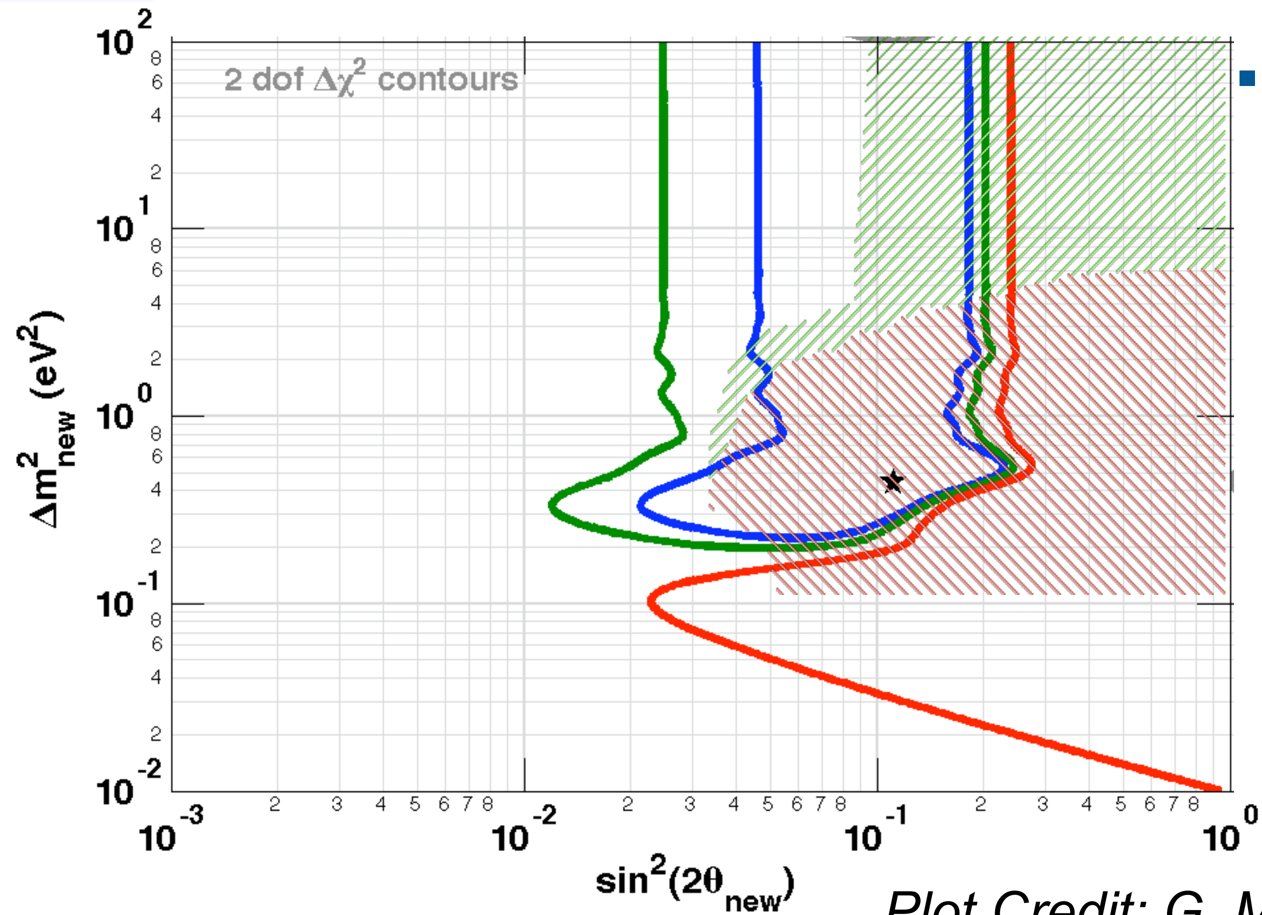


- **Provides a strong test of the low Δm^2 region excluded by Bugey3 shape**

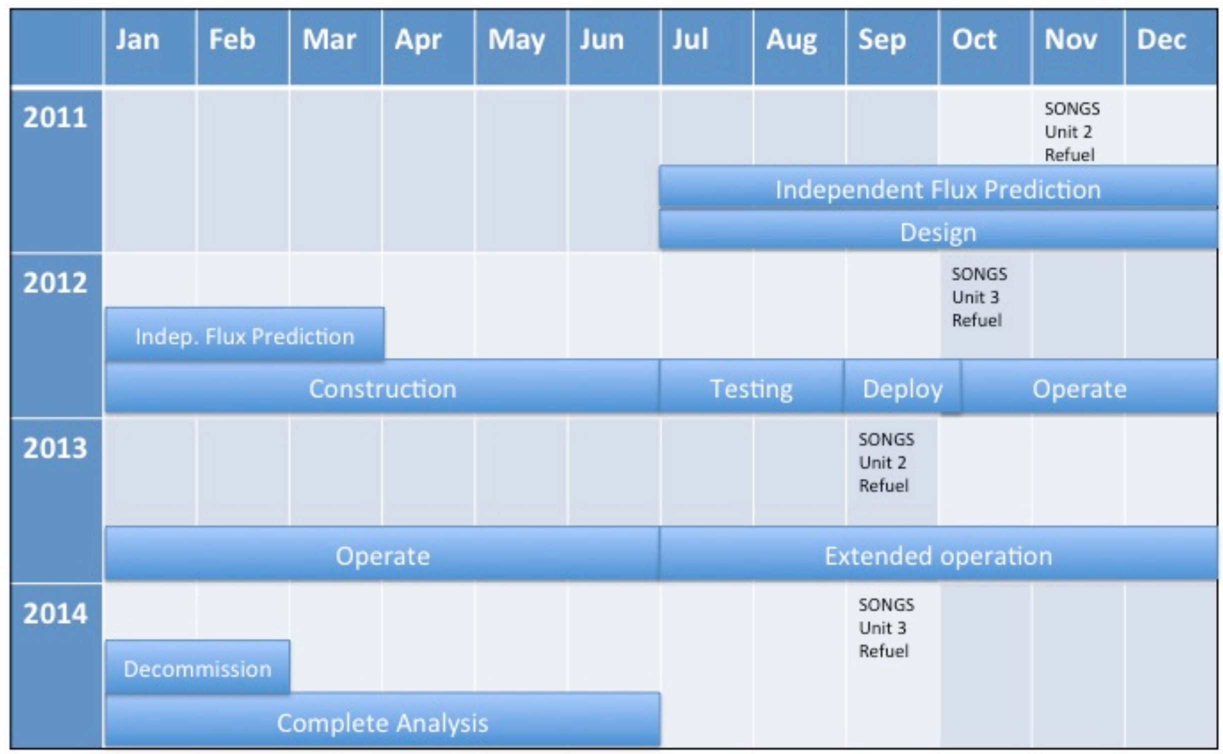
Plot Credit: G. Mention

Schedule

- Reactor refueling outages are key – background measurement:
  - Unit 3 in Oct. 2012
  - Unit 2 in Sept. 2013

- Given our recent experience, 15-18 months from design to deployment seems feasible

- Could have first results within ~9 months of data taking



Conclusion

- The “RAA” must be investigated. We propose to so so by:
  - An independent reactor antineutrino flux prediction
  - A relatively rapid and inexpensive experimental measurement
- Our group has considerable relevant expertise:
  - Reactor simulations
  - Precision beta spectrum generator code
  - Compact antineutrino detector design
  - Access to a favourable reactor deployment site
- The SONGS site is optimal for a power reactor deployment
  - High flux, good overburden, and narrow $\Delta L/L$
- SCRAAM would rapidly exclude a large fraction of the “RAA” allowed phase space, and have discovery potential in the “best-fit” region